THE ESTIMATION OF SEA-BREEZE FRONT VELOCITY OVER COASTAL URBAN USING HIMAWARI-8 IMAGES: A CASE STUDY IN JAKARTA

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ABSTRACT

The sea breeze is a meteorological phenomenon that occurs due to the contrast temperature between land and oceans. The propagation velocity of sea breeze is influenced strongly by e.g., synoptic wind and geographical conditions. Therefore, it is important to understand the relationship between the spatial distribution of sea breeze velocity and the surface characteristic, for instance over urbanized and less-urbanized coastal areas. When the sea breeze propagates inland, a cumulus cloud-line will form in the vicinity of the sea breeze front (SBF). Previous studies have successfully detected the cloud-line automatically using the morphological-snake algorithm. In this paper, the SBF velocity was estimated using Himawari-8 satellite images. The proposed method segmented the cloud-line data points using a clustering approach, named machine learning-based k-means++, on the level-set obtained from snake algorithm. The SBF speed was estimated by calculating the haversine distance of the segmented cloud-line points that propagate over time. The comparison of estimated cloud-line speed with SBF speed measured at two observation sites, namely the headquarter office of the Ministry of Marine and Fisheries (KKP) near the coast (106.846E, 6.124S) and Environmental Management Agency (BPL) at the city center (106.835E, 6.226S), reveals the root mean square errors 1.39 m/s and 1.41 m/s, respectively which shows that the model estimation is quite good. And the propagation direction was mainly southward. Our results are beneficial for enhancing a deeper understanding of local weather patterns in coastal urban areas such as Jakarta.

Keywords: Himawari-8, sea-breeze front, cumulus cloud-line

1. Introduction

Sea breeze is a meteorological phenomenon that occurs due to contrast temperature between land and oceans [1]. Although for the tropics the onset time of sea breezes does not vary so much, the direction and speed of sea breeze propagation is very much influenced by many factors, such as geographical factors and surface conditions [1, 2]. The sea breeze functions as a ventilation for air pollution and also cooling for mitigation the increasing air temperature (known as urban heat island phenomenon) in the coastal area [1]. Therefore, the spatial distribution of the characteristics of the sea breeze is essential [ref alvin and anis]. This spatial information can be obtained by remote sensing techniques such as the Himawari-8 satellite observation [3-5].

When the sea breeze propagates inland, under certain conditions, a cumulus cloud-line (here in after, cloud-line) is formed in the vicinity of the sea breeze front [6]. This cloud-line is a cloudiness feature that can be detected on satellite imagery and can be used as a proxy for the location of the sea breeze front (SBF) [3, 4, 7]. Hence, the SBF propagation can be traced from the cloud-line movement. Previous studies have successfully detected the cloud-line automatically with a computer vision approach for edge detection, using the called snake algorithm [5, 7].

The benefit and importance of SBF propagation study and cloud-line detection has also been widely discussed to help us achieve a deeper understanding of local weather pattern [8-12]. He (2021) discussed the characteristics of SBF over the river delta region, while Junnaedhi (2021) and He (2020) investigated the sea breeze event and its influence in different types of locations. Bernardino (2021) and Ribeiro (2018) stressed the effect of the sea breeze regime on urban areas and its propagation influence. These studies shed light on the importance of sea breeze characteristic investigation that helps to reveal fundamental knowledge about different local weather patterns.

Using our proposed technique of combining snake algorithm and k-means++ segmentation, the arrival time of the SBF was able to be estimated automatically. However, it is still not able to estimate the velocity of the SBF propagation directly in automatic manner. This paper aims to estimate the direction and speed which are properties of SBF propagation over coastal-urban areas using Himawari-8 images automatically.

2. Methods

Study area. We focus on Jakarta region, the capital city of Indonesia, and surrounding region (indicated by rectangular in Figure 1). Jakarta is located on a plain area bordered by the Java Sea to the north and the highlands with various elevation (800 to 2000 meter) to the south [13]. In the dry season, prevailing synoptic winds from the southeast, forging very conducive condition to the formation of the sea breeze fronts. While penetrating landward in the afternoon (around 3-4 PM local time), sea breezes often merge with the orographic wind from the mountainous area in the south. The mean wind speed during sea breeze day can reach around 6-7 m/s [2].

Sea-breeze-front arrival-time dataset. In this work**,** the sea-breeze days and SBFs arrival-time dataset reported by [5] study was utilized. In their study they retrieved the SBFs information from 53 sea-breeze days in July-August-September (JAS) months of 2017 and 2018 by detecting the passing time of the cloud-lines at two observation sites (KKP and BPL) and validated them with ground measurement. The dataset includes the two-dimentional (2D) spatial distribution of the cloud-lines as the proxy of the SBF location. They used the normalized albedo of visible images (Band 03) of Himawari-8 geostationary satellite and implemented the morphological snakes algorithm for cloud-line detection. For our analysis, among 53 days we selected 36 days when SBF was clearly inland propagation observed at both KKP and BPL sites (see Table 1).

Cloud-line velocity estimation. The previous study by [5] implemented the morphological-snake algorithm [14] to detect the cumulus cloud-line in the visible band (B03) of Himawari-8 images. Since the curve evolution using the morphological-snake algorithm is carried out implicitly, we need to populate the control points explicitly to estimate the propagation velocity. For that purpose, we implemented the cloud-line segmentation using k-means++ approach to objectively select the representative control points among the cloud-line. The propagation speed was then estimated by calculating the haversine distance between two cloud-lines of two consecutive images. The detailed procedures are given as follows:

K-means++ segmentation. The cloud-lines of the sea breeze front consist of a number of data points with longitudes and latitudes information. The length of cloud-lines may change over time. To track the changes of cloud lines in terms of distance and velocity, we have to provide a paired data points from each compared cloud-line. We propose a segmentation approach to cloud-line data points using a dynamic K-means++ clustering method. Clustering is one of the unsupervised types of machine learning beneficial for extracting the natural grouping of a large number of data in many applications [15, 16,17].

K-means++ constructs a number of k desired clusters/segmentation from a set of data points X where the distance of all points to the farthest cluster center are calculated as follows:

$$\mu_i = \max_{(j:1 \to m)} \left\| x_i - c_j \right\|^2 \tag{1}$$

Where μ_i and *m* are the distance of the farthest cluster center to the x_i point and the number of already selected cluster centers respectively. $x \in X$. And c_j denotes the j-th the cluster center.

Hence, the K-means++ method aims to minimize the following objective function:

$$\textstyle\sum_{x \in X} \min_{c \in C} |x - c|^2 \tag{2}$$

Haversine distance. In order to calculate the distance of cloud lines, we use the haversine function computed directly from the longitude and latitude of each distinct pairs of cloud line points.

Hence, the spherical distance is calculated as follows:

$$d = 2r\, arcsin \left(\sqrt{ sin^2\left(\frac{\psi_2 - \psi_1}{2}\right) + \cos(\psi_1)\cos(\psi_2) sin^2\left(\frac{\sigma_2 - \sigma_1}{2}\right) } \right) \tag{3}$$

Where *d* is the spherical distance between two points on Earth and *r* is the Earth's radius. The latitude of point 1 and 2 are defined in radians as ψ_1 and ψ_2 respectively. The corresponding radian longitude of point 1 and 2 are denoted as σ_1 and σ_2 respectively. The approximate radius of Earth is 3,959 miles or 6,373 km.

Figure 1. Study Area.

Table 1. Arrival time dataset of Sea-breeze front estimated from ground measurement sites. The time is in local time (LT). The distance between KKP-BPL is 11.41 km. (Dataset from [5] study).

No	Date SBD	SBF arrival KKP	SBF arrival BPL	SBF speed [m/s]
1	2017-07-24	10:10:00	13:10:00	1.06
2	2017-07-28	11:40:00	13:00:00	2.38
3	2017-08-03	10:30:00	13:40:00	1.46
4	2017-08-05	09:40:00	13:40:00	0.79
5	2017-08-06	09:10:00	14:40:00	0.58
6	2017-08-08	10:40:00	14:20:00	0.86
7	2017-08-11	09:20:00	12:00:00	1.19
8	2017-08-15	11:20:00	12:20:00	3.17
9	2017-08-31	10:20:00	12:00:00	1.9
10	2017-09-01	10:50:00	13:10:00	1.36
11	2017-09-02	12:30:00	14:30:00	1.58
12	2017-09-04	10:30:00	12:10:00	1.9
13	2017-09-09	09:10:00	12:10:00	1.06
14	2017-09-10	09:30:00	12:50:00	0.95
15	2017-09-15	09:10:00	11:30:00	1.36
16	2017-09-19	09:40:00	14:40:00	0.63
17	2017-09-23	10:10:00	11:50:00	1.9
18	2018-07-08	11:40:00	13:40:00	1.58
19	2018-07-23	09:20:00	11:30:00	1.46
20	2018-07-24	09:10:00	12:00:00	1.12
21	2018-07-25	10:20:00	13:20:00	1.06
22	2018-07-26	11:40:00	13:20:00	1.9
23	2018-07-30	09:50:00	12:00:00	1.46
24	2018-07-31	10:30:00	12:50:00	1.36
25	2018-08-12	09:30:00	13:30:00	0.79
26	2018-08-13	11:30:00	14:00:00	1.27
27	2018-08-14	11:10:00	14:00:00	1.12
28	2018-08-16	09:50:00	14:20:00	0.7
29	2018-08-17	09:20:00	11:20:00	1.58
30	2018-08-22	10:10:00	11:10:00	3.17
31	2018-09-02	10:10:00	11:30:00	2.38
32	2018-09-04	11:30:00	13:00:00	2.11
33	2018-09-23	12:20:00	13:30:00	2.72
34	2018-09-24	10:10:00	14:10:00	0.79
35	2018-09-29	11:00:00	12:50:00	1.73
36	2018-09-30	11:00:00	13:50:00	1.12

Calculating bearing. Velocity of the sea breeze front contains not only the speed but also the direction of movement. Additional to the distance calculation between two points of cloud line on Earth, we estimate the direction of sea breeze from the known start point to another end point by computing the following formula:

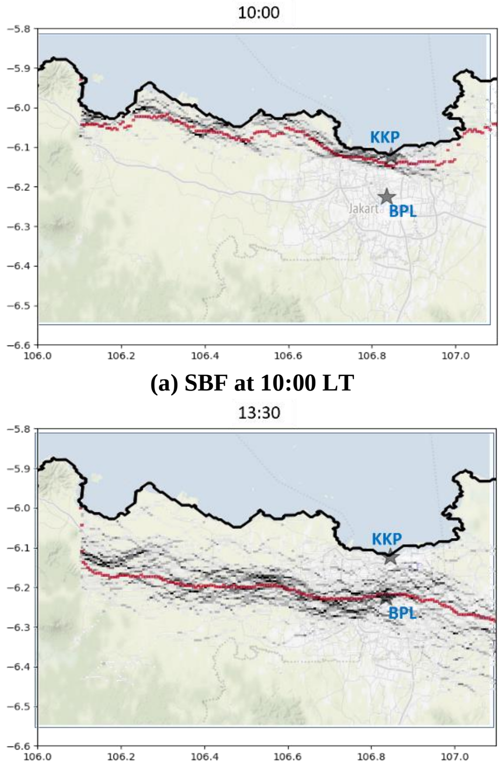
$$\tau = arctan2\begin{pmatrix} sin\Delta\delta cos\psi_2, \\ cos\psi_1 \cdot sin\psi_2 - \\ sin\psi_1 \cdot cos\psi_2 \cdot cos\Delta\delta \end{pmatrix} \quad (4)$$

Where τ is the direction from the start point of ψ_1 latitude and δ_1 longitude to the destination point of ψ_2 latitude and δ_2 longitude. Δδ is the longitude difference between those two points. The direction is calculated by assuming the orthodrome on the Earth shape.

3. *Result and Discussion*

As reported by [5], the uncertainty location of cloud-line passage among each detection results can be reduced by calculating the average locations. The density function can be implemented to calculate mean passage time (as the proxy of mean SBF arrival time at certain pixels/locations. Figure 2 shows the example for spatial distribution of mean SBF arrival time derived from the cloud-lines passage time on satellite images. The mean of the cloud-lines passage time was estimated by Kernel Density Function.

Figure 3 depicts the spatial distribution for SBF inland penetration from 9 AM to 4 PM LT (per 10 minutes). At 4 PM the SBF could penetrate until 40 km in outskirts west of Jakarta City but only 25 km in city centre. The spatial distribution of this inland propagation provides us information the various arrival time on the various geographical conditions such as between urbanized and non-urbanized area.



(a) SBF at 10:00 LT

(b) SBF at 13:30 LT

Figure 2. The example plots for spatial distribution of sea-breeze fronts estimated from the location of the cloud-lines (grey lines) at 10:00 and 13:30 LT, respectively. Red lines indicated the mean location of the SBFs observed at certain time. (Plotted using dataset from [5])

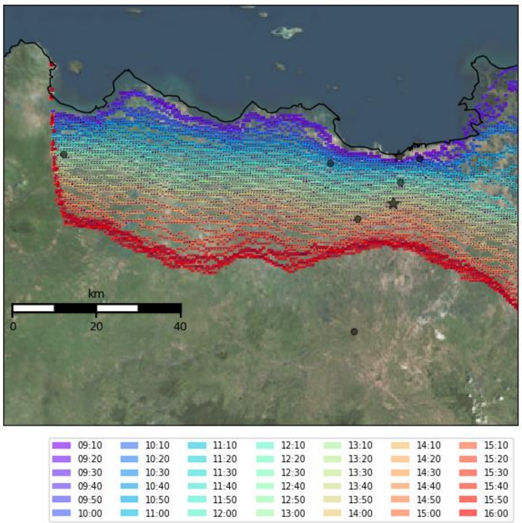


Figure 3. Spatial distribution of mean SBF arrival time estimated by the cloud-lines. Dataset from [5] study.

Based on the SBF arrival time (observation dataset from [5]) shown in Table 1, among the SBD cases that were analysed, the sea breezes usually reach KKP and BPL at 10:00 and 13:30 LT, respectively. And the mean propagation speed of SBF between these two observation sites can be estimated to be around 1.5 m/s.

To improve the previous study by [5], in this paper we attempt to estimate the speed and direction of the SBF automatically. For the speed, first, we calculated the percentile of the cloudline speed for each hour of all 36 SBD cases. The result is shown in Figure 4. We found wide range of speed within 9:00 to 10:00 even the outliers (0 m/s and speed > 7 m/s) are already excluded. The reason for this exclusion is that SBF speed will not exceed the mean wind speed during SBD (6-7 m/s [2]). Minimum speed was at 13:00 which coincided with mean arrival time of SBF at BPL site. The graph also shows slightly increase again after 13:00 to afternoon.

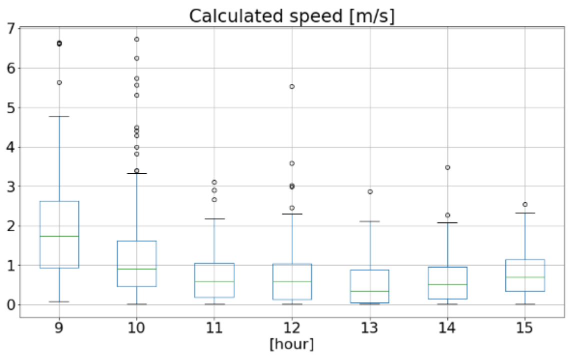
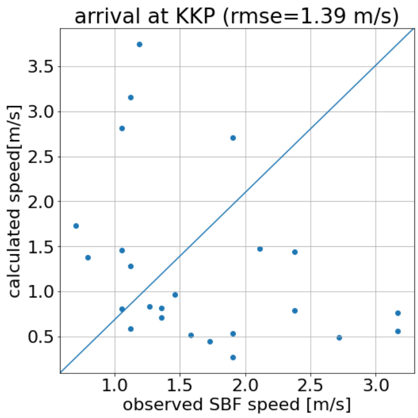


Figure 4. Statistical result of SBF speed for 36 cases of sea-breeze days in the hourly time manner.

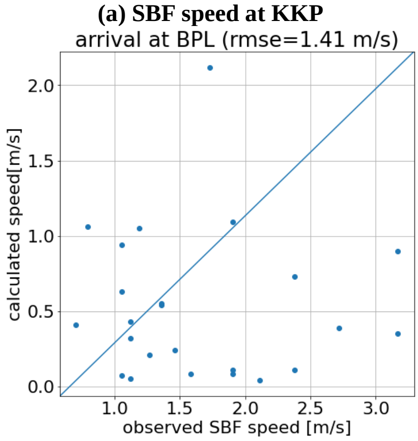
And to show the robustness of the method, we estimated the average propagation speed of the entire cloud-line and compared it with the SBF speed measured by ground measurement. Figure 5 reveals the comparison between the SBF speed and the calculated speed at each arrival time at KKP and BPL.

Table 2 shows the estimated velocity of sea breeze front in terms of speed and direction at arrival time of each location, KKP and BPL respectively using our proposed approach. By comparing the estimated and measured speed of the SBF at each location, the root mean squared errors (RMSE) are 1.39 m/s and 1.41 m/s at KKP and BPL respectively. The small value of RMSE indicates that the difference between the estimated and observed speed is generally good.

Finally, Figure 6 shows the estimated direction of the mean SBF (detail time evolution in each hour is shown in Figure 3). The propagation of the cloudline was traced, and three points among that segmented cloudline member were plotted. Three representative times (10:00, 12:00 and 15:00 local time) were selected to estimate the propagation.



(a) SBF speed at KKP



(b) SBF speed at BPL

Figure 5. Scatter plot of SBF speed for comparison between in situ-measurement (observed) and satellite (estimated). Dataset from [5] study.

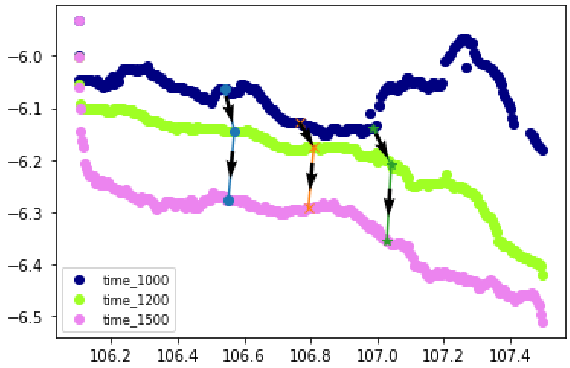


Figure 6. The estimated direction of sea-breeze-front. Three representative times (10:00, 12:00 and 15:00 LT) were selected to estimate the propagation.

Table 2. Estimated sea breeze front velocity at KKP and BPL sites. The units for speed and direction are m/s and degree, respectively.

	Observed	Estimated		
Data SBD	SBF speed	SBF speed at KKP	SBF speed at BPL	SBF direction
2017-07-24	1.06	1.46	0.07	179.93
2017-07-28	2.38	1.44	0.11	179.72
2017-08-11	1.19	3.75	1.05	181.38
2017-08-15	3.17	0.76	0.9	179.78
2017-08-31	1.9	0.27	1.09	180.09
2017-09-01	1.36	0.82	0.54	179.78
2017-09-02	1.58	0.52	0.08	180.15
2017-09-04	1.9	2.71	0.11	179.12
2017-09-09	1.06	2.81	0.94	181.04
2018-07-23	1.46	0.97	0.24	179.85
2018-07-24	1.12	3.16	0.32	178.99
2018-07-25	1.06	0.81	0.63	179.98
2018-07-26	1.9	0.53	0.08	179.9
2018-07-31	1.36	0.71	0.55	179.75
2018-08-13	1.27	0.83	0.21	179.8
2018-08-14	1.12	0.59	0.05	180.15
2018-08-16	0.7	1.73	0.41	179.4
2018-08-17	1.58	14.83	0.21	175.87
2018-08-22	3.17	0.56	0.35	180.2
2018-09-02	2.38	0.79	0.73	180.28
2018-09-04	2.11	1.48	0.04	179.55
2018-09-23	2.72	0.49	0.39	180.15
2018-09-24	0.79	1.38	1.06	179.53
2018-09-29	1.73	0.45	2.12	179.9
2018-09-30	1.12	1.28	0.43	179.77

4. Conclusion

In this study, we addressed the estimation challenges of the sea breeze front (SBF) velocity over the coastal urban region and proposed a new estimation approach utilizing the Himawari-8 satellite imagery data. Our proposed approach constructs a segmentation of cloud line data points using dynamic k-means++ on the level-set result of the morphological-snake algorithm. By calculating the haversine distance and bearing of the segmented cloud line data points that change over time, we were able to estimate the SBF velocity in the Jakarta Capital City of Indonesia and its surrounding region. Our study provides potential benefit to contribute in the understanding of spatial characteristics of the sea breeze.

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